**CREATION, EVALUATION AND IMPLEMENTATION OF A
PRECIPITATION-TYPE FORECASTING SYSTEM**

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Abstract

This COMET proposal describes a two-year project, beginning on 6/1/00, that will create, evaluate, and implement the first precipitation-type probabilistic forecast system, using ensemble forecasting and consensus forecasting concepts, at the Hydrometeorological Prediction Center (HPC) and the Storm Prediction Center (SPC). The research component of this project will evaluate the quality of various precipitation-type algorithms and investigate various ensemble forecasting concepts in applying the collection of algorithms. The operational component of the project will create probabilistic forecasts of each precipitation type diagnosed by the algorithms and consensus forecasts of the most probable precipitation type. After sufficient development and testing at the HPC and the SPC, these forecasts will be made available routinely to all National Weather Service (NWS) offices within two years, provided approval is granted by the NWS.

I. Overview

Precipitation-type forecasting remains a difficult task for even the most experienced forecasters because of the uncertainties associated with forecasting the evolution of winter weather systems that produce snow, rain, ice pellets, and freezing rain, as well as inadequate atmospheric data sampling, a complete knowledge of precipitation microphysics, and limited techniques to evaluate high resolution model data. The importance of forecasting these events accurately is illustrated by a set of statistics compiled the Office of Meteorology, which reports

that between 1990 and 1997, ice storms were responsible for 65 fatalities, 2742 injuries, and roughly two billion dollars worth of damage in the United States. To address this problem, the NWS has placed the highest research priority on quantitative precipitation estimation (QPE) and quantitative precipitation forecast (QPF) information, including precipitation type and probabilistic QPF.

In current operational environments, forecasters have few techniques to assess accurately and efficiently the potential for various types of winter precipitation, despite the recent availability of high-resolution model data. As a result, many forecasters still rely on early precipitation-type forecasting techniques using numerical model output at mandatory levels, commonly referred to as "thickness" rules, and Model Output Statistics (MOS; Bocchieri 1980), which are dependent on particular model quirks. The quality of forecasts using thickness rules, however, is limited since the use of 1000-500 mb, 1000-850 mb and 850-700 mb layers often are unable to resolve thin warm layers that may have a significant effect on the precipitation type. Additionally, the surface pressure at most locations during winter weather events is less than 1000 mb, making these techniques less than satisfactory.

The Nested Grid Model (NGM) MOS system has provided forecasters with probabilistic forecasts of precipitation type since 1993, and has been shown to be accurate (critical success index 0.8 from 18–42 h) at distinguishing between rain and snow forecasts. The MOS system, however, is much less accurate at predicting freezing precipitation (Erickson 1995). More importantly, the regression equations used by the MOS system are created using a significant amount of historical model runs and must be recalculated when model changes occur. Since NCEP frequently modifies its current mesoscale model, the Eta, it is no longer feasible to use the MOS system with the output from this numerical model.

Recently, operational forecast offices have received output from the cloud prediction schemes in the Eta and the Rapid Update Cycle (RUC) models. These schemes explicitly represent the various phases of water within clouds and have the potential to provide forecasts of precipitation type at the ground. To date, however, very little research has been done to verify the accuracy of such schemes and their precipitation-type forecasts since microphysical measurements of clouds are extremely difficult to obtain. While we expect that future modifications to cloud schemes will improve precipitation-type forecasting, we believe that there exists another way to obtain accurate precipitation-type information from numerical models that can be implemented quickly and provide a performance standard for future fully-objective systems. The success of the precipitation-type algorithms is because of the considerable extent to which the detailed moist thermodynamic vertical structure reflects and governs cloud and precipitation microphysics. Unlike statistically-based MOS-type products, the algorithm-based products can adapt to model upgrades more quickly.

Some of the problems associated with the current forms of precipitation-type numerical guidance can be avoided by using a computer algorithm that utilizes the high vertical resolution of the current generation of mesoscale models and is based on the physical processes that determine precipitation type. During the last decade, several algorithms that meet these criteria have been developed (Baldwin et al. 1994; Bourgouin 1992; Czys et al. 1999; Ramer 1993; Cortinas and Baldwin 1999). In areas of precipitation, these algorithms determine the most likely type of precipitation at the ground by examining the characteristics of saturated cold (temperature $\leq 0°C$) and warm layers (temperature $> 0°C$) encountered by falling hydrometeors. If the air near the ground is subfreezing and a warm layer that is sufficiently deep to completely melt frozen precipitation exists above it, then freezing rain is diagnosed; otherwise, if the warm

layer only partially melts the frozen precipitation, then ice pellets are diagnosed. If no warm layer is present and the warmest temperature in the vertical is cold enough to support active ice nuclei, then snow is diagnosed. If a warm layer that is sufficiently deep exists near the ground, then rain is diagnosed.

Despite the similarities, the algorithms differ from each another in two ways, the critical environmental characteristics used to define particular precipitation types and the amount of detail related to the microphysics of hydrometeors. The algorithms developed by Baldwin et al. (1994), and Bourgouin (1992) differ in the way the warm and cold layers are characterized, as well as the critical values (determined empirically) used to distinguish between different precipitation types. Moreover, they do not make any assumptions about the characteristics of the hydrometeors, except the initial phase--solid or liquid--as they begin to descend. The Ramer (1993) algorithm, although similar to the Baldwin et al. (1994) and the Bourgouin (1992) algorithms, determines the precipitation type based on an estimate of the ice fraction contained in the hydrometeors and a simple empirically-derived equation.

The algorithm developed by Czys et al. (1996) models the melting process of an individual hydrometeor, assuming that all hydrometeors begin as ice spheres of a given size (radius=4 microns). If a warm layer exists, the algorithm determines the average temperature of the layer and computes the amount of time required to melt completely the hydrometeor at that temperature. Next, the algorithm calculates the hydrometeor residence time in the warm layer. If the residence time is less than the complete melting time, then partial melting occurs; otherwise, complete melting occurs in the warm layer. The algorithm determines the precipitation type at the ground using criteria similar to the algorithms described previously. The algorithm developed by Cortinas and Baldwin (1999) is similar to the Czys et al. (1996)

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algorithm except that instead of solving the hydrometeor melting/freezing equation using the average temperature and depth of the entire warm layer, it solves the equation using thermodynamic data at each model vertical level.

A preliminary evaluation of these algorithms, as well as an algorithm that uses a set of thickness rules, found several interesting results (Cortinas and Baldwin 1999):

- The algorithms that use all the available thermodynamic data are more skillful than the one that applies a set of traditional thickness rules to data from three vertical levels.

- No one algorithm can skillfully diagnose all types of precipitation.

- Creating an consensus diagnosis out of the algorithm output produces a diagnostic system with good resolution, although the reliability is not perfect.

Although the Cortinas and Baldwin (1999) study examined the quality of the algorithms using observed rawinsonde and surface data, their results suggest that the quality of these algorithms may be good using mesoscale model output as well. This hypothesis is also supported by the studies of Baldwin et al. (1994) and Ramer (1992) who, with a limited amount of data, showed that their algorithms were able to differentiate reasonably well between different precipitation types using mesoscale model output. The results from Cortinas and Baldwin (1999) are similar to those of Brooks et al. (1996), who showed that the Baldwin et al. (1994) algorithm, calculated using an ensemble of Eta members, correctly identified areas where the threat of freezing rain was high during a particular event.

Given these results, it is reasonable to expect that forecasts from many different algorithms, using output from one or more different numerical models, can be combined to form a probabilistic forecast of precipitation type. The studies of Thompson (1977), Sharman et al. (1999) for predicting turbulence and Vislocky and Fritsch (1995) for predicting various weather

elements all provide additional support to the hypothesis that a optimal combination of forecasts from two or more independent sources often produces a better forecast than any of the individual forecasts. In all the studies, the authors found that the consensus forecasts performed better than the individual forecasts.

In this two-year study, we propose to establish a system that will use numerical model output from the Eta and the Rapid Update Cycle (RUC) to generate probabilistic guidance to NWS forecasters concerned with precipitation-type forecasting. Because of the guidance responsibilities of the Hydrometeorological Prediction Center (HPC) and the Storm Prediction Center (SPC) and the critical need of this type of forecast system at these locations, initial development and testing of the system will involve meteorologists at HPC and SPC. *To our knowledge, this system will provide the National Weather Service with the first operational system that generates probabilistic forecasts of precipitation type, as well as the most probable type, at locations across the United States.*

II. Statement of Work

a. Objectives

The objectives of this study are to:

- determine the quality of six precipitation-type algorithms using observations and mesoscale model output;
- determine if the quality of several precipitation-type algorithms can be improved by modifications based on surface and rawinsonde observations;
- develop a high-quality (in the statistical sense) technique for making probabilistic forecasts of precipitation type with numerical model output and an ensemble of precipitation-type algorithms from one or more models;

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- identify efficient methods of displaying probabilistic forecast output of precipitation type for forecasters at the HPC and the SPC;

- help EMC incorporate the algorithms into their model output processing routines in order to distribute the precipitation-type output to all NWS offices;

- familiarize forecasters with the meteorological processes that are associated with the formation of various precipitation types.

b. Proposed Methodology

Initial efforts in the development of the precipitation-type forecast system will focus on data collection and algorithm testing. During the entire cold seasons of 2000-2001 and 2001-2002, numerical model output, rawinsonde data, and surface observations will be collected in order to evaluate the quality and skill of the precipitation-type algorithms. Like Goldsmith (1990), we will examine various attributes of the forecast quality, such as the accuracy, bias, reliability, resolution, discrimination, and sharpness by using the joint distribution of forecasts and observations (see Wilks 1995), for each algorithm and the probabilistic forecast created with the algorithm ensemble.

Coincident with the data collection period will be an algorithm refinement phase during which 15 years (1976-1990) of historical rawinsonde and surface data (available at the National Severe Storms Laboratory) will be used to systematically determine the optimal set of parameters for each algorithm. Tests during the refinement phase will also provide information about the sensitivity of these algorithms to parameter changes and suggest which physical processes may be important in the determination of precipitation type. The real-time evaluation of the algorithms will be run on a workstation located at HPC. An initial set of graphical

products will be created and distributed to HPC and SPC for display on their N-AWIPS workstations.

We will devise a method of producing probabilistic forecasts using output from all of the algorithms applied to the Eta model solution (from 0–48 h) and the RUC model solution (from 0–12 h). Initially, we will determine the probability of a particular precipitation type as the percentage of ensemble members that predict the same type, a method similar to that used by Brooks et al. (1996). For example, suppose that, using the Eta model output, half of the algorithms predicted snow at a particular location, whereas the other algorithms predicted freezing rain. In this situation, the probabilistic forecast for that location would be 50% for freezing rain and 50% for snow. These probabilities inform forecasters about the degree of uncertainty associated with the algorithms. We will test other linear combinations of the ensemble members as well.

The forecast system will predict the most probable type of precipitation every hour of the model forecast based upon a weighted consensus forecast (see Thompson 1977; Vislocky and Fritsch 1995; Sharmen et al. 1999). The initial set of algorithms will consist of those developed by Baldwin et al. (1994), Bourgouin (1992), Cortinas and Baldwin (1999), Czys et al. (1996), and Ramer (1993), as well as an algorithm based on thickness rules. The weights assigned to the individual algorithms will be determined by using multiple linear regression and surface and rawinsonde observations from 1976-1990. Unlike the system described by Sharmen et al. (1999), we do not anticipate devising a system that requires the weights to be recomputed for each model cycle since the aim of our project is to develop a forecast system that is independent of the numerical model data used by the algorithms. We will use the Kuipers skill score (Wilks 1995) to determine the skill of the consensus forecast and each of the algorithms. The

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probabilistic and most probable type forecasts will be computed initially at over 1000 sites across the United States since the complete model vertical data are only made available at these sites.

Once results are available from the analysis of the ensemble and algorithms, we will work with the EMC to submit a request to the NWS Committee on Applied Forecasting Techniques and Implementation (CAFTI) to incorporate the algorithms into the model post processing routines. Given CAFTI approval, we will assist EMC with the programming needed to incorporate the algorithms into the post processing routine, this will allow the algorithm and probabilistic output to be distributed to all NWS offices.

In order to design and implement a forecast system that is useful to forecasters, we will require some participation from HPC and SPC forecasters. Throughout the study, forecasters will be asked to provide subjective evaluations of the algorithms, the probabilistic forecasts, and the most probable type forecasts, as well as comments on the usefulness of the graphical output. During each year of the project, the principle investigators will visit each site at least once to discuss the forecast system and other issues relevant to the project with forecasters and management at HPC and SPC. The principle investigators also will be available to discuss the algorithms with forecasters at any time throughout the year. We will also create a web-based information system that describes the algorithms and the study for HPC and SPC forecasters.

c. Expected outcomes and potential benefits

At the end of this project, NWS forecasters will have a fully-functioning precipitation-type forecast system to help them interpret quickly and efficiently the enormous amount of numerical model guidance they receive. We believe that the positive impact of this project will be realized across the National Weather Service by:

- an improvement in the quality of the winter weather products issued by NWS meteorologists and by other meteorologists who use NWS forecasts;

- an increase in the lead time given before the occurrence of hazardous winter weather;

- a reduction in the false alarm rate associated with winter weather products, particularly those associated with icing events, issued by national centers and local forecast offices;

- an improvement in forecaster understanding of the important physical processes associated with the formation of various precipitation types.

Aside from the benefit of this project on NWS operations, the results from this study will contribute to other research being conducted on short-range ensemble forecasting and consensus forecasting, particularly with respect to the predictability of sensible weather phenomena.

d. Schedule

The tasks defined in the methodology section will begin on June 1, 2000, and be accomplished over a two-year period, encompassing portions of three calendar years and three fiscal years. During the first year, we will use archived model output, rawinsonde data, and surface observations to test the quality of the algorithms and the ensemble forecast; experiment with various ways of generating the probabilistic forecasts from the ensemble, based on observations; and examine various methods of displaying the output. During the first year, we will also run all the algorithms during the winter season in real-time and distribute the output to HPC and SPC forecasters for them to evaluate. Throughout the season, we expect to make modifications to the algorithms, the ensemble, and the graphical displays based on forecaster evaluations and other quality attributes of the current system configuration.

During the second year, we will work with EMC to incorporate the algorithms into the post processing routines, provided approval is given by CAFTI. We will compute verification

statistics for the second winter season and create a real-time verification system that will give forecasters current verification information on the performance of the algorithms and the ensemble forecasts. We will also create web-based documentation about the algorithms that can be placed on the EMC web site and viewed by all NWS forecasters.

Tasks	FY 1 (Project starts 6/1/00) J J AS	FY 2 OND JFMAMJ J AS	FY 3 (Project ends 5/31/02) ONDJFMAM
Collect data, evaluate algorithms and modify if necessary.	XXXX	XXXXXXXXXXXX	XXXXX
Implement initial system at HPC and forecaster evaluation process.	XXXX		
Develop and test probabilistic and consensus forecast techniques.	XXXX	XXXX	
Modify system based on analysis results and forecaster evaluations.		XXXXXX	
Implement, evaluate, and test real-time verification system.		XXXXXX	
Move algorithms to post processing		XXX	X
Evaluate final forecast system.			XXXXXXX
System becomes operational			X

V. Budget

We request funding to support the salaries of each University of Oklahoma investigator and a web development specialist. A request is made for funding to support one research trip per investigator per year to visit the HPC and the University of Oklahoma, or for the University of Oklahoma investigators to attend a scientific conference. In addition to the time contributed by NWS personnel who are listed as co-PIs on this project, Peter Manousos, Scientific Operations Officer, HPC, and Jon Racy, Mesoscale Forecaster, SPC, will contribute to the effort of this project by assisting with the coordination and system evaluation within the forecast operations at

HPC and SPC. Total contribution from P. Manousos will total 40 hours annually and 10 hours from J. Racy.

The National Weather Service will donate roughly 200 hours of personnel time annually as well as publication costs and travel expenses for K. Brill and P. Manousos. In addition, NCEP will donate the use of 65 GB of disk storage and tapes valued at approximately $1500 per year.

VI. Project Personnel

Dr. John Cortinas Jr., PI, is a Research Meteorologist for the Cooperative Institute for Mesoscale Meteorological Studies and an Adjunct Assistant Professor in the School of Meteorology, both at the University of Oklahoma. His office is physically located in the same building as the SPC. Dr. Cortinas's research interests are in the area of hazardous winter weather and other operationally relevant issues. His recent research projects include the development of climatologies of hazardous winter weather, an investigation into the role of the Great Lakes on the mesoscale organization of ice storms, and the development of a precipitation-type algorithm for use in weather forecasting. He has been involved with experimental forecasting activities at the SPC and has conducted many winter weather training seminars for forecasters at local NWS offices, the HPC, and the SPC.

Mr. Keith F. Brill, Co-PI, is a Physical Scientist in the Development and Training Branch of the HPC of the NCEP under the National Weather Service. Prior to his current position, he was a meteorologist in the EMC of NCEP from 1993 to April 1999. Mr. Brill has developed meteorological applications software for model diagnostics and verification. This work has resulted in the delivery of software systems and the publication of research papers.

Mr. Michael E. Baldwin, Co-PI, is a Research Assistant for the Cooperative Institute for

Mesoscale Meteorological Studies at the University of Oklahoma. His primary duties involve

developing new verification techniques for mesoscale numerical prediction models, and

implementing a relocatable mesoscale modeling system for the SPC. He has acquired expertise

on many aspects of the Eta Model, precipitation analysis, and verification, while working as a

support scientist for General Sciences Corporation from 1991 through1999 at the EMC of NCEP.

References

Baldwin, M., R. Treadon, and S. Contorno, 1994: Precipitation type prediction using a decision tree approach with NMCs mesoscale eta model. *Tenth Conf. On Numerical Weather Prediction*, Portland, OR, AMS 30–31.

Bocchieri, J.R., 1980: The objective use of upper air sounding to specify precipitation type. *Mon. Wea. Rev.,* **108,** 596–603.

Brooks, H. E., J. V. Cortinas, Jr., P. Janish, and D. Stensrud, 1996: Applications of short-range numerical ensembles to the forecasting of hazardous winter weather. *Fifteenth Conf. on Weather Analysis and Forecasting,* Norfolk, VA, Amer. Meteor. Soc, 127–130.

Bourgouin, P., 1992: Criteria for determining precipitation types. Preprints, *Fourth Workshop on Operational Meteorology,* Whistler, BC, AES/CMOS, 460–469.

Cortinas, J.V., Jr., and M. E. Baldwin, 1999: A preliminary evaluation of six precipitation-type algorithms for use in operational forecasting. Postprint, *Sixth Workshop on Operational Meteorology,* Halifax, Nova Scotia, Environment Canada, in press.

Czys, R., R. Scott, K.C. Tang, R. W. Przybylinski, and M. E. Sabones, 1996: A physically based, nondimensional parameter for discriminating between locations of freezing rain and ice pellets. *Wea. Forecasting*, **11,** 591–598.

Erickson, M., 1995: Evaluating NWS precipitation type forecasts. *Sixth Conf. on Aviation Weather Systems,* Dallas, TX, Amer. Meteor. Soc., 219–224.

Goldsmith, B. S., 1990: NWS verification of precipitation type and snow amount forecasts during the AFOS era. NOAA Tech. Mem. NWS FCST 33, National Weather Service, Camp Springs, MD, 28 pp.

Ramer, J., 1993: An empirical technique for diagnosing precipitation type from model output. Preprints, *Fifth International Conf. On Aviation Weather Systems,* Vienna, VA, AMS, 227–230.

Sharman, R., C. Tebaldi, and B. Brown, 1999: An integrated approach to clear-air turbulence forecasting. Preprints, *Eighth Conf. on Aviation, Range, and Aerospace Meteorology,* Dallas, TX, AMS, 68-71.

Thompson, P. D., 1977: How to improve accuracy by combining independent forecasts. *Mon. Wea. Rev.*, **105,** 228–227.

Vislocky, R. L., and J. M. Fritsch, 1995: Improved model output statistics forecasts through model consensus. *Bull. Amer. Meteor. Soc.,* **76,** 1157–1164.

Wilks, D., 1995: Statistical methods in the atmospheric sciences. Academic Press, 467 pp.